

2011 GSRP Final Report: Nonlinear Electrostatic Properties of Lunar Dust

By Stacy A. Irwin, Florida Institute of Technology, Melbourne, FL, 32901

Research Advisor: Samuel T. Durrance

Technical Advisor: Carlos I. Calle, Kennedy Space Center

Summary

A laboratory experiment was designed to study the induction charging and charge decay characteristics of small dielectric particles, or glass beads. Initially, the goal of the experiment was further understanding of induction charging of lunar dust particles. However, the mechanism of charging became a point of greater interest as the project continued. Within an environmentally-controlled acrylic glove box was placed a large parallel plate capacitor at high-voltage (HV) power supply with reversible polarity. Spherical 1-mm and 0.5-mm glass beads, singly, were placed between the plates, and their behaviors recorded on video and quantified. Nearly a hundred trials at various humidities were performed. The analysis of the results indicated a non-linear relationship between humidity and particle charge exchange time (CET), for both sizes of beads. Further, a difference in CET for top-resting beads and bottom-resting beads hinted at a different charging mechanism than that of simple induction.

Results from the 1-mm bead trials were presented at several space science and physics conferences in 2008 and 2009, and were published as a Master's thesis in August 2009. Tangential work stemming from this project resulted in presentations at other international conferences in 2010, and selection to attend workshop on granular matter flow 2011.

Work Completed

Data were collected by a video camera aimed at an experimental apparatus what was designed and built in the laboratory (see Figure 1). The setup allowed variable plate separation, placement of a single bead roughly in the center of the bottom plate, and open sides which allowed digital video recording of the beads' activity. The plates were kept at 1.0 ± 0.05 cm separation for all trials. Subject placed in the apparatus were 1 ± 0.05 mm and later 0.5 ± 0.025 mm diameter spherical borosilicate glass beads. The apparatus was enclosed in a humidity controlled glove box at ambient room temperature. We maintained humidity with an NIST calibrated logger, to within about 2% of the desired set-point, and temperature was kept at $22 \pm 2^\circ\text{C}$. Before beginning a trial the air was charge neutralized with an ionizing blower. The DC power supply applied $+18.00 \pm 0.025$ kV to the top plate, while the bottom plate was grounded. Digital video files were later stepped through with ULead Video Studio editing software, and motions of the beads were identified in a spreadsheet as "top [still]," "bottom [still]," "upward," "downward," or "off." The last classification indicated the bead had moved off of the apparatus.

An IDL program was written to interpret the motions and associate staying times with location (top or bottom plate). A bead's staying time or CET was defined as its charge exchange time (CET), the time required for it to acquire enough charge to maintain an electrostatic force strong enough to overcome the attractive polarization force (and the downward gravitational force if on the bottom plate), and accelerate toward the opposite plate. Data of beads exhibiting rare and unusual behavior, likely due to

contaminants, were discarded. CETs were grouped by humidity and bead size. The statistical software Minitab 15 was used to graphically display distributions of CETs as histograms (see Figure 2), test for normality, determine a suitable distribution (lognormal), and obtain confidence intervals for the mean CET for each humidity level. This mean was taken as a characteristic CET for each group and plotted on a graph of CET vs. humidity for each group (see Figure 3). Regression analysis was performed and an equation of the line-fit recorded.

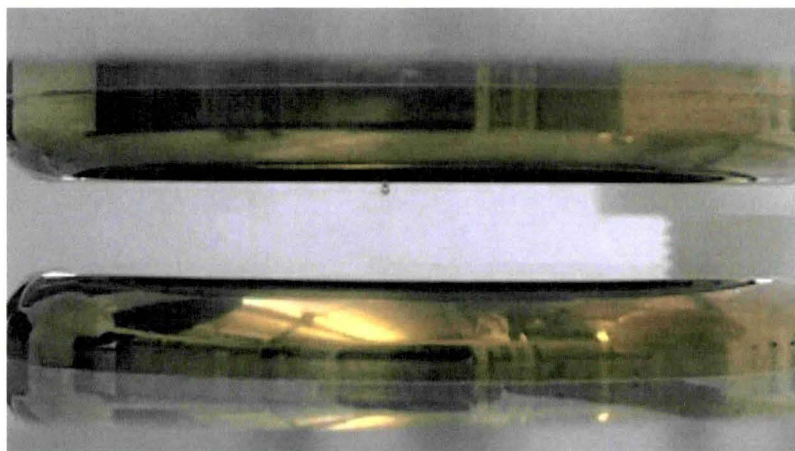


Figure 1. A view of the experimental apparatus with a bead on the top plate, as seen by the camera.

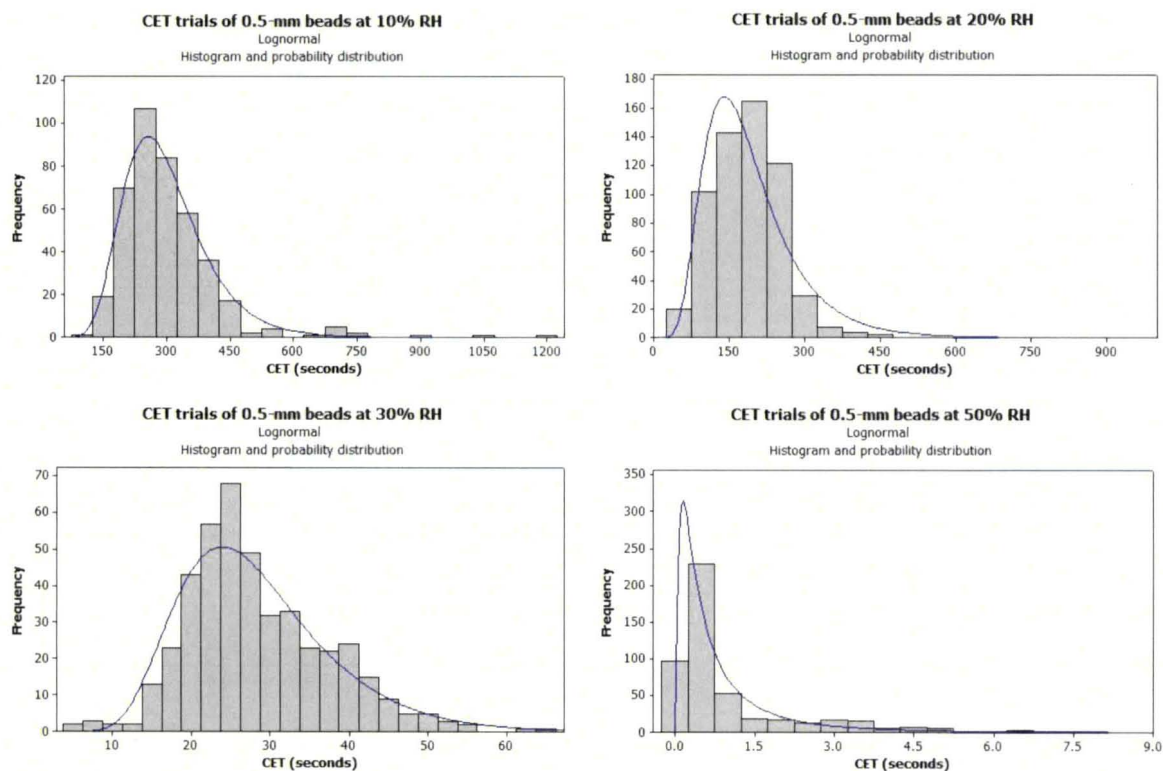


Figure 2. Histograms from Minitab 15 representing the distributions of 0.5 mm bead CETs. RH values refer to set-point humidities.

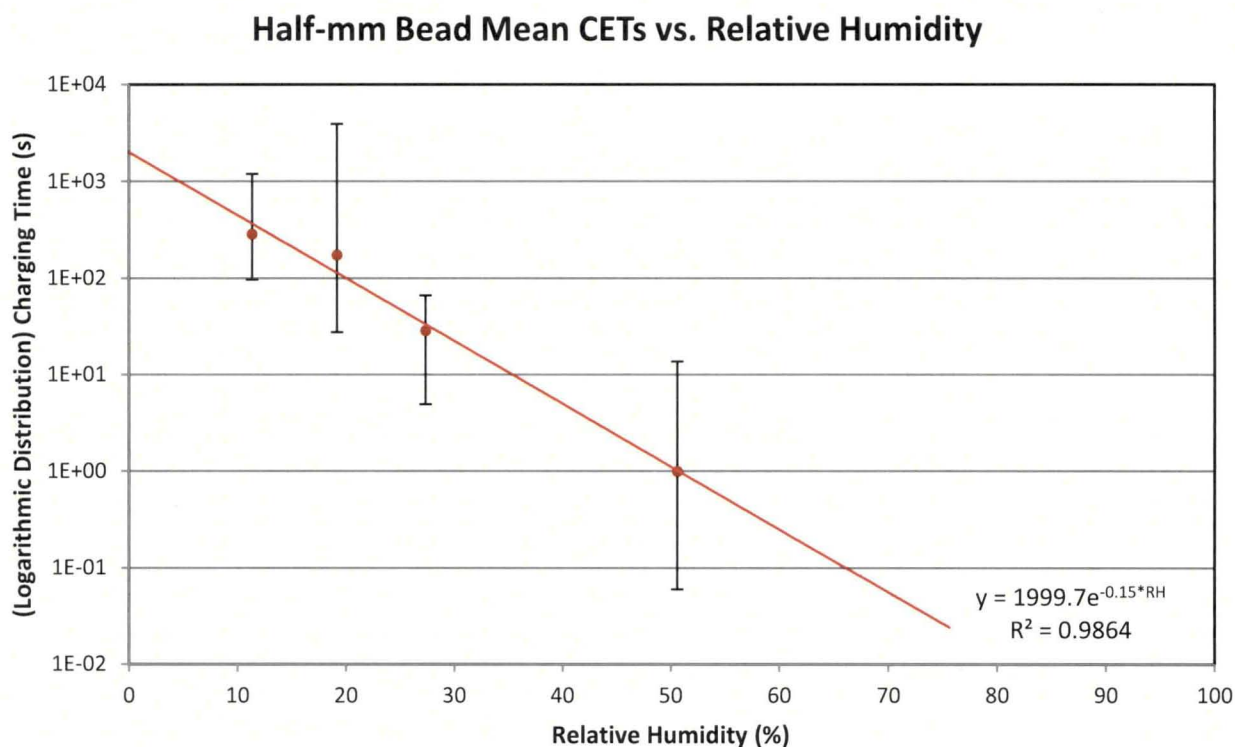


Figure 3. A regression line describing the relationship between CET and relative humidity for half-mm beads, extrapolated from the four data points collected so far for 0.5-mm bead trials. Error bars represent the range of values in the trials.

Lessons Learned

Several obstacles were overcome during the course of the project. First, it was realized early on that if several beads were placed on the apparatus, no recognizable trend in charging times emerged. This was due, likely, to the beads' own interfering electric fields as their net charge and their near neighbor's net charge changed. This led to the decision to observe the beads singly.

Contamination of beads by oil, dust, etc. was an issue at various points, prompting a strict cleaning regimen for later trials, especially for the 0.5-mm bead trials.

Sources for error in CET included the degree to which the parallel plates were exactly parallel, minute deformities on the faces of the plates, the roundness of the beads, and whether a bead had been previously used for the experiment. If future experiments continue along these lines, it is suggested that "new" untested beads are used for each trial, "used" beads are discarded, temperature and humidity are more closely regulated and recorded, and that a pure, or nearly pure nitrogen atmosphere is maintained inside the glove box.

Other improvements to the experimental set up and procedure include the use of a heat lamp (rather than a vacuum convection oven) to evaporate the layer of adsorbed water on the beads' surface, administering better control of light sources in the area of the experiment, and image/video processing software to automate the identification of bead behavior as it relates to time.

Related and Future Work

Future work using this apparatus could consist of experiments varying temperatures, humidities, plate separations, and bead sizes.

One of the more interesting effects that could use further study was the consistent difference in the CETs for top resident beads and bottom resident beads. It would be though that the top charging time would be shorter than the bottom, with gravity as an aiding force to accelerate the bead downward, but some other mechanism is preventing this from happening. See Figure 4. One way to investigate this would be to simply reverse the polarity of the DC power supply and determine if the opposite trend is observed.

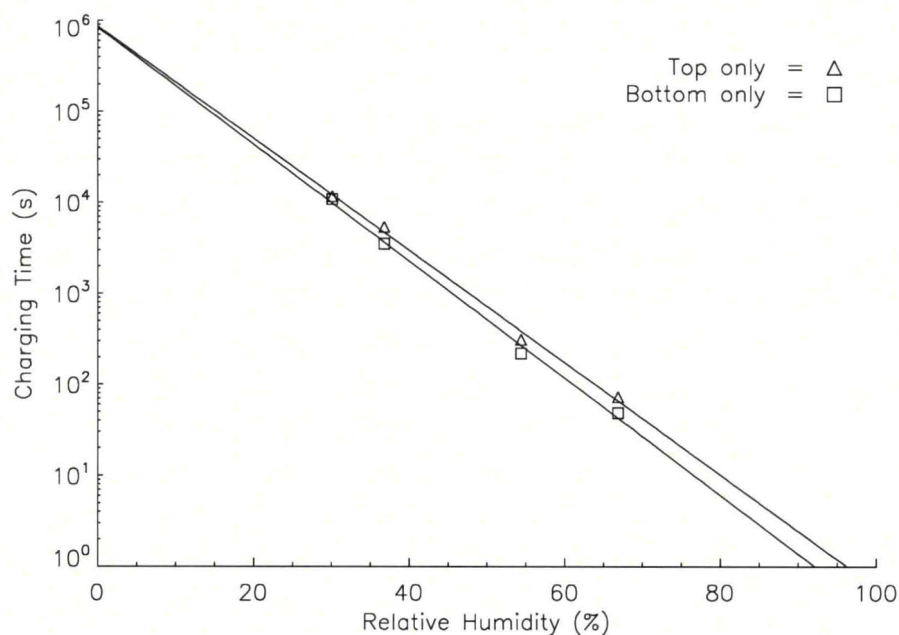


Figure 4. Regression lines describing CET versus relative humidity for 1-mm beads, grouped by their resident charging time on the top (triangle) or bottom (square) plate. Error bars are omitted for clarity.

In the master's thesis, several similar experiments identified in journal papers were compared to the results of this project. Despite their use of an ensemble of particles, the characteristic time to movement, for example, had a similar observable nonlinear property, as it related to humidity.

Work from this project indirectly lead to participation in the Mars Desert Research Station (MDRS) experiment, a Mars analogue habitat in a remote desert in Utah. Research from this experience

was presented at the Global Lunar Conference in Beijing, China, in June 2010, and the 61st International Astronautical Congress in Prague, Czech Republic, in September 2010.

Additionally, the recipient was selected to participate in a workshop at the University of Maryland at College Park, called GRF11: The 2011 Interdisciplinary Summer School - Granular Flows: From Simulations to Astrophysical Applications. Many exciting topics and methods of data collection were introduced here, and have become the foundation of a PhD dissertation on the topic of grain agglomeration in protoplanetary disks.

During early 2011, 2-3 weeks were spent at the Electrostatics and Surface Physics Laboratory assisting visiting scientists with their work. The remainder of the third year's internship was not fulfilled so that the time could be committed to preparation for PhD qualifying examinations, with permission from Dr. Carlos Calle.

Conclusion

A nonlinear trend was found in the charging times of small dielectric particles that represented lunar dust, as humidity was varied in a controlled atmosphere. These results were new but consistent with previous studies examining electrostatic charge, potential, or current.

In particular, the GSRP has enabled this recipient to complete a Master's degree, attend professional conferences, and engage in similar research both at NASA, ESA, and elsewhere. Work has already begun on a PhD topic regarding grain growth in protoplanetary disks, and the relevance of electrostatic forces acting on them.